# LIGHT EMITTING DIODE HEADLAMP AND HEADLAMP ASSEMBLY

## PRIORITY CLAIM

[0001] The present application claims priority to U.S. Provisional Patent Application, Serial Number 60/414,980, filed October 1, 2002, which is incorporated by reference herein, and U.S. Provisional Patent Application, filed September 30, 2003, which is incorporated by reference herein.

## FIELD OF THE INVENTION

[0002] The subject invention relates to vehicular lights. More particularly, the embodiments of the subject invention are directed to a headlamp and headlamp assembly for vehicles that uses light emitting diodes as a light source.

## BACKGROUND OF THE INVENTION

[0003] Most motorized vehicles currently use incandescent or high-intensity discharge sealed-beam headlamps and headlamp assemblies. For example, many heavy-duty vehicles use incandescent, four (4) inch by six (6) inch, rectangular, sealed-beam headlamps in a quad lamp assembly. In one embodiment of the present invention, four (4) inch by six (6) inch, rectangular, sealed-beam low beam and high beam headlamps, that use light emitting diodes as a light source, form a quad lamp assembly designed to retrofit the aforementioned incandescent four (4) inch by six (6) inch quad packages. By way of further example, other vehicles use incandescent, seven (7) inch round, combined low/high beam headlamps in a dual lamp assembly.

Accordingly, in an alternate embodiment of the invention, seven (7) inch round, combined low/high beam headlamps, that use light emitting diodes as a light source, form a two-lamp assembly designed to retrofit the incandescent, seven (7) inch round packages. Moreover, embodiments of the present invention may also be used as OEM (Original Equipment Manufacturer) parts.

[0004] The embodiments of the subject invention that are disclosed herein are designed to satisfy the Society of Automotive Engineers (SAE) Standard J1383 for high beam and low beam vehicular headlamps. SAE Standard J1383 specifies certain photometric requirements, including luminous intensity requirements, for vehicular lamps functioning as headlamps.

[0005] The Department of Transportation (DOT), in its Federal Motor Vehicle Safety Standards, 49 C.F.R. §571.108 (2000), ("FMVSS 108") regulates all lamps, reflective devices, and associated equipment. FMVSS 108 can be found at www.nhtsa.dot.gov and is hereby incorporated by reference in its entirety. DOT Standard 1383 (part of FMVSS108) adopts the Society of Automotive Engineers (SAE) Standard J1383 (December 1996) for motor vehicle headlamps.

[0006] SAE Standard J1383 defines a headlamp as a "lighting device providing an upper and/or lower beam designed to provide illumination forward of the vehicle." SAE Standard J1383 further defines a sealed beam headlamp assembly as "a headlamp assembly which includes one or more sealed beam headlamps." A low beam is a "beam intended to illuminate the road ahead of a vehicle when meeting or following another vehicle." A high beam is a "beam intended primarily for distant illumination for use when not meeting or following other vehicles." SAE Standard J1383 also requires

that the color of the emanating light produced by a headlamp shall be white as defined in SAE Standard J578.

[0007] SAE Standard J1383 also specifies certain requirements for vehicular lamps functioning as headlamps, including minimum and/or maximum luminous intensity requirements. According to the aforementioned standards, a minimum and/or maximum luminous intensity must exist at various points in the illumination zone to be in compliance. These specific photometric requirements for vehicular low beam and high beam headlamps, as set forth in SAE Standard J1383, are included hereinbelow.

**Table 1: PHOTOMETRIC SPECIFICATION - LOW BEAM**

| Low Beam | Minimum (cd) | Maximum (cd) |
|---|---|---|
| 10U to 90U, $45^0$ R to $45^0$ L | | 125 |
| 8L to 8 R, H to 4U | 64 | |
| 4L to 4R, H to 2U | 125 | |
| 1U to 1-1/2 L to L | | 700 |
| 1/2U to 1-1/2L to L | | 1000 |
| 1/2D to 1-1/2L to L | | 3000 |
| 1-1/2U to 1R to R | | 1400 |
| 1/2U to 1R, 2R, 3R | | 2700 |
| 1/2D to 1-1/2R | 8000 | 20000 |
| 1D to 6L | 750 | |
| 1-1/2D to 2R | 15000 | |
| 1-1/2D to 9L and 9R | 750 | |
| 2D to 15L and 15R | 700 | |
| 4D to 4R | | 8000 |

**Table 2: PHOTOMETRIC SPECIFICATION - HIGH BEAM**

| High Beam | Minimum (cd) | Maximum (cd) |
|---|---|---|
| 2U to V | 1500 | |
| 1U to 3R and 3L | 5000 | |
| H to V | 20000 | 75000 |
| H to 3R and 3L | 10000 | |
| H to 6R and 6L | 3250 | |
| H to 9R and 9L | 2000 | |
| H to 12R and 12L | 500 | |
| 1-1/2D to V | 5000 | |
| 1-1/2D to 9R and 9L | 1500 | |
| 2-1/2D to V | 2000 | |
| 2-1/2D to 12R and 12L | 750 | |
| 4D to V | | 12500 |
| Maximum Beam Candela[(1)] | 30000 | |

1. The highest candela reading found in the beam pattern

[0008] SAE J578, entitled "Color Specification", sets forth the definition for white light as applied to headlamps. The definition applies to the overall effective color of light emitted by a headlamp in any given direction and not to the color of the light from a small area of the lens. In SAE J578, the fundamental requirements for color are expressed as chromaticity coordinates according to the CIE (1931) standard colorimetric system.

[0009] Pursuant to SAE J578, the following requirements for white light shall apply when measured by the tristimulus or spectrophotometric methods, as are well known in the art.

**Table 3: WHITE LIGHT (ACHROMATIC)**

The color of light emitted from the headlamp shall fall within the following boundaries:
$x = 0.31$ (blue boundary)
$x = 0.50$ (yellow boundary)
$y = 0.15 + 0.64x$ (green boundary)
$y = 0.05 + 0.75x$ (purple boundary)
$y = 0.44$ (green boundary)
$y = 0.38$ (red boundary)

[0010] SAE J1383 standard and SAE J578 standard can also be found at www.sae.com and are hereby incorporated by reference in their entirety, as is FMVSS 108, 49 C.F.R. §571.108 (2000).

[0011] As mentioned above, one embodiment of the subject invention relates to a headlamp quad assembly that incorporates four (4) individual light emitting diode headlamps (i.e. 2 low beam lamps and 2 high beam headlamps). In this embodiment, each individual headlamp is a four (4) inch by six (6) inch, rectangular sealed-beam lamp. In an alternate embodiment, a dual headlamp assembly incorporates two (2) combined, high/low beam headlamps, wherein each individual light emitting diode headlamp is a seven (7) inch round sealed-beam lamp. In still another embodiment of the two-lamp assembly, each individual headlamp is a five (5) inch by seven (7) inch rectangular sealed-beam lamp. In each of the embodiments, the individual lamps forming a headlamp assembly emit white light (as defined above).

## BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Figure 1 is a diagrammatic, front-end view of a heavy-duty vehicle provided with a light emitting diode headlamp assembly according to one embodiment of the present invention.

[0013] Figure 2 is an exploded perspective view of a low beam headlamp according to one embodiment of the present invention.

[0014] Figure 3 shows a vertical cross section of the low beam headlamp in Figure 2.

[0015] Figures 4A-4C illustrate a cross-sectional, perspective and plan view, respectively, of a reflector subassembly according to one embodiment of the present invention.

[0016] Figure 5A illustrates a vertical cross-sectional view of inner and outer light transmissive members according to one embodiment of a low beam headlamp.

[0017] Figure 5B illustrates a longitudinal cross-sectional view of inner and outer light transmissive members according to one embodiment of the low beam headlamp.

[0018] Figures 5C-5D illustrate a perspective and top plan view of the inner light transmissive member shown in Figures 5A-5B.

[0019] Figure 6 shows a rear plan view of the outer light transmissive member for the low beam headlamp shown in Figures 1-2.

[0020] Figures 7A-7F illustrate partial longitudinal and vertical cross-sections of the optical surfaces formed on the outer light transmissive member shown in Figure 6.

[0021] Figure 8 illustrates a longitudinal cross-sectional view of inner and outer light transmissive members according to one embodiment of the high beam headlamp illustrated in Figure 1.

[0022] Figure 9 shows a rear plan view of the outer light transmissive member for the high beam headlamp illustrated in Figure 1.

[0023] Figures 10A-10B show partial longitudinal and vertical cross-sections of the optical surfaces formed on the outer light transmissive member shown in Figure 9.

[0024] Figures 11A-11C illustrate a top plan view, bottom plan view and cross-sectional view, respectively, of the housing in one embodiment of the headlamp assembly.

[0025] Figure 12 illustrates one embodiment of the drive circuit in one embodiment of the headlamp assembly.

[0026] Figure 13A illustrates the manner in which the reflector subassembly and inner light transmissive member direct light emitted from the light emitting diodes.

[0027] Figure 13B illustrates the manner in which the outer light transmissive member in a high beam headlamp directs light.

[0028] Figure 14 is a diagrammatic, top plan view of the vehicle in Figure 1.

[0029] Figures 15A-15B illustrate the light pattern created on an imaginary surface.

[0030] Figures 16A-C illustrate an alternate embodiment of the invention, a 7-inch round combined low/high beam headlamp.

## DETAILED DESCRIPTION OF THE DRAWINGS

[0031] For the purpose of promoting an understanding of the present invention, references are made in the text hereof to embodiments of a low beam and high beam light emitting diode headlamp and headlamp assembly, some of which are illustrated in the drawings. It is nevertheless understood that no limitations to the scope of the invention are thereby intended. One of ordinary skill in the art will readily appreciate that modifications such as these involving the shape of the low and high beam headlamps, type or number of light emitting diodes, number of reflector units, or type and placement of optical elements of the lens, do not depart from the spirit and scope of the present invention. Some of these possible modifications are mentioned in the

following description. In the embodiments depicted, like reference numerals refer to identical structural elements in the various drawings.

[0032] Figure 1 is a diagrammatic, front-end view of a heavy-duty vehicle 1 provided with a preferred embodiment of the present invention, namely a sealed beam headlamp assembly 4 that uses light emitting diodes as a light source. In the embodiment shown here, headlamp assembly 4 is a four (4) inch by six (6) inch, quad headlamp package. Accordingly, as shown here, headlamp assembly 4 comprises four individual sealed headlamps: two (2) low beam headlamps 70 and two (2) high beam headlamps 170, each of the four individual headlamps utilizing light emitting diodes as a light source. In this embodiment, the low and high beam headlamps are identical, except for the outer lens that distributes the light appropriately to satisfy the SAE requirements.

[0033] In the embodiment shown in Figure 1, and as described herein, headlamps 70 function as low beam headlamps that satisfy the photometric, dimensional, color and other requirements for low beam headlamps as set forth in SAE Standard J1383. Similarly, headlamps 170 function as high beam headlamps that satisfy the photometric, dimensional, color and other requirements for high beam headlamps as set forth in SAE Standard J1383. For example, in the embodiment shown here, low beam headlamps 70 and high beam headlamps 170 are rectangular in shape and approximately four (4) inches by six (6) inches to comply with the dimensional requirements of SAE Standard J1383. One of ordinary skill in the art will readily appreciate, however, that a sealed-beam headlamp assembly according to the instant invention can also comprise combined low/high beam headlamps with alternate

shapes and/or dimensions and still comply with SAE Standard J1383. For example, in one alternate embodiment, a headlamp assembly utilizes two combined low beam/high beam headlamps that are round in shape with a seven (7) inch diameter (see Figures 16A-C). Alternatively, the headlamp assembly utilizes two combined low beam/high beam headlamps that are rectangular in shape and approximately five (5) inches by seven (7) inches (not shown).

[0034] Moreover, the overall effective color of light emitted by low beam headlamps 70 and high beam headlamps in any given direction is white to satisfy SAE Standard J1383. As indicated hereinabove, SAE Standard J578 expresses the fundamental requirements for white light as chromaticity coordinates according to the CIE (1931) standard colorimetric system (see Table 3 hereinabove). Accordingly, for purposes of this disclosure, white light is defined according to the chromaticity coordinates as set forth in the CIE (1931) standard colorimetric system.

[0035] Referring further to Figure 1, in an embodiment of the quad headlamp assembly, two (2) headlamps 70 are operatively arranged as the two outer headlamps of headlamp assembly 4 to perform the low beam function and two (2) headlamps 170 are operatively arranged as the two inner headlamps of headlamp assembly 4 to perform the high beam function. Referring further to Figure 1, each low beam headlamp 70 and each high beam headlamp 170 is a separate unit with a separate housing that is mounted individually to the front end of vehicle 1, thereby forming headlamp assembly 4. However, in alternate embodiments of the invention, headlamp assembly 4 can comprise low beam headlamp 70 and high beam headlamp 170 as separate units that are joined together prior to mounting or each pair of low beam headlamp 70 and high

beam headlamp 170 can share a single housing. The method and manner of mounting headlamp assembly 4 to vehicle 1 are well known to one of ordinary skill in the art. Moreover, it is contemplated that low beam headlamp 70 and high beam headlamp 170 may retrofit headlamps in existing vehicles 1 or, alternatively, low beam headlamp 70 and high beam headlamp 170 may be included in the original equipment of a manufactured vehicle 1.

[0036] Figure 2 is an exploded perspective view of an individual low beam headlamp 70. Low beam headlamp 70, in this embodiment of the invention, is comprised of a housing 6, a reflector subassembly 11, a plurality of high-flux light emitting diodes 12, an outer light transmissive member 13, and a generally planar support member 9. Headlamp 70 further comprises a plurality of inner light transmissive members 17, disposed behind outer light transmissive member 13 (and, therefore, not shown here). A drive circuit 5, discussed in more detail hereinbelow, is also provided for headlamp 70.

[0037] In Figure 2, headlamp 70 is shown to include a total of six (6) high-flux light emitting diodes 12. In this embodiment, light emitting diodes 12 preferably are configured in a two-dimensional array having two horizontal rows and three vertical columns to create a 2 x 3 matrix. In this preferred embodiment, support member 9 is generally planar and light emitting diodes 12 are mounted on support member 9 with their primary axis horizontal to the ground and parallel with the longitudinal axis of vehicle 1, such that the light emitted from each of light emitting diodes 12 is directed away from support member 9. In an alternate embodiment of a combined high/low

beam headlamp, light emitting diodes 12 are configured in an array that forms a circular pattern and are mounted on a circular-shaped support member (See Figure 16C).

[0038] In all of the embodiments disclosed herein, a high-flux light emitting diode is defined as a light emitting diode capable of producing a minimum flux of at least 50-55 lumens, and an average flux of approximately 70 lumens. For example, but not intending to be limiting, a plurality of 3-Watt Luxeon™ Lambertian-style light emitting diodes, manufactured by LumiLeds Lighting B.V., are used in a preferred embodiment.

[0039] Figure 3 shows a cross section along axis A-A (see Figure 2) of low beam headlamp 70. Referring to Figure 3, headlamp 70 includes housing 6 and outer light transmissive member 13. In this embodiment, and as will be described in more detail below, outer light transmissive member 13 is a lens with at least one optical surface for directing light emitted from light emitting diodes 12. Outer light transmissive member 13 also functions to form a cover for housing 6, defining a three-dimensional space 7 therebetween. In a preferred embodiment, outer light transmissive member 13 is hermetically sealed to housing 6 with an adhesive that additional functions as a sealant. For example, one of ordinary skill in the art will readily appreciate that RTV silicone or urethane can be used as the adhesive.

[0040] Referring further to Figure 3, headlamp 70 again is shown to comprise reflector subassembly 11, high-flux light emitting diodes 12, and support member 9. Headlamp 70 is also shown to include a plurality of inner light transmissive members 17 fixedly secured to light transmissive member 13.

[0041] In Figure 3, it can be seen that light emitting diodes 12 are disposed at the base of reflector subassembly 11 and mounted to a generally planar, support member

9. Support member 9 is a circuit board in the embodiment shown here. More specifically, support member 9 is an aluminum core circuit board that is mounted directly on housing 6.

[0042] In alternate embodiments, support member 9 can be a conventional circuit board. In such an embodiment (not shown), light emitting diodes 12 are secured to support member 9 via mounting posts with heat transfer properties, wherein the mounting posts correspond to holes in support member 9. Such a mounting method is described in U.S. Patent No. 5,857,767 (Hochstein), U.S. Patent No. 6,428,189 (Hochstein) and U.S. Patent 6,582,100 (Hochstein). In still another embodiment, a very thin Fiberglass Reinforced Polyester circuit board can be used as support member 9, which would provide adequate heat transfer away from light emitting diodes 12 and, thereby, eliminate the need for an aluminum circuit board or mounting posts.

[0043] Figure 4A illustrates a cross-sectional view of reflector subassembly 11. Figure 4B illustrates a perspective view of reflector subassembly 11. Figure 4C illustrates a top planar view of reflector subassembly 11. In the embodiment shown in Figures 4A-4C, reflector subassembly 11 is a unitary reflector subassembly. Reflector subassembly comprises a plurality of reflector units 11*a* arranged in a plurality of rows. Each individual reflector unit 11*a* has an aperture 26, which corresponds to one light emitting diode 12. Specifically, reflector subassembly comprise six (6) reflector units 11*a* forming a 2 x 3 array such that each individual reflector unit 11*a* corresponds to an individual light emitting diode 12. In an alternate embodiment of a combined high/low beam headlamp, reflector subassembly combines fourteen (14) individual reflector units

forming a circular arrangement such that each individual reflector unit corresponds to one of fourteen (14) individual light emitting diodes (see Figures 16A-C).

[0044] In a preferred embodiment, each individual reflector unit 11*a* is a parabolic revolution with a 6 mm focal length. More specifically, but not intended to be limiting, in the embodiment shown here, distance G-G is approximately 44 mm; distance F-F is approximately 44 mm, and each aperture 26 has a diameter of 24 mm. More generally, each reflector unit 11*a* collects and collimates a portion of the light emitted from the corresponding light emitting diode 12 (see Figure 13A). The resulting light rays are substantially parallel to the longitudinal axis of the lamp and directed toward said outer light transmissive member.

[0045] In a most preferred embodiment, reflector subassembly 11 is constructed of a metalized thermoplastic material. Specifically, in a preferred embodiment, reflector subassembly 11 is a single piece of molded polycarbonate plastic that is subsequently metalized with aluminum. In alternate embodiments, reflector subassembly 11 can be constructed of a naturally reflective material, or can be coated with other reflective materials, such as white or silver paint. In addition, although the embodiment shown here depicts a unitary reflector subassembly with six reflector units, in an alternate embodiment each reflector unit 11*a* can be molded as a plurality of individual reflectors.

[0046] Figure 5A illustrates a cross section of outer light transmissive member 13 along vertical line A-A, as shown in Figure 2, and Figure 5B illustrates a cross section along longitudinal line $B_2$-$B_2$. As can be seen in Figures 5A-5B, light transmissive member 13 has an inner surface 21 and outer surface 22.

[0047] A plurality of annular extensions 20 corresponding to light emitting diodes 12 are integral to outer light transmissive member 13, extending laterally from inner surface 21 toward reflector subassembly 11. Each annular extension 20 functions as an alignment mechanism for an inner light transmissive member 17. In a preferred embodiment, there are six (6) annular extensions 20 and six (6) inner light transmissive members 17, each corresponding to one of the six (6) light emitting diodes 12. Inner light transmissive members 17 are fixedly secured (as described below) to annular extensions 20 to maintain the correct position relative to a corresponding light emitting diode 12. More specifically, annular extensions 20 align said inner light transmissive members 17 relative to said light emitting diodes 12 such that each of said plurality of inner light transmissive members 17 is positioned substantially parallel to outer light transmissive member 13 and in front of a corresponding light emitting diode 12.

[0048] In alternate embodiments, other alignment mechanisms for light transmissive members 17 may be used. For example, although not shown, one could use three-legged extensions that laterally extend toward the reflector subassembly or disc-like extensions from the outer light transmissive member that laterally extend toward the reflector subassembly. In addition, one could use a plurality of annular extensions or three-legged extensions that lateral extend from the planar substrate (not shown).

[0049] Inner light transmissive members 17 are collimating lenses with a 24 mm back focal length. Figures 5c-5d illustrate a perspective and cross-sectional view of one light transmissive member 17, respectively. Each inner light transmissive member 17 captures the light rays that bypass reflector units 11*a*, and then concentrates and

directs the captured light rays toward outer light transmissive member 13. More specifically, each inner light transmissive member 13 captures the light rays emitted in a cone extending approximately forty-four (44) degrees from a corresponding light emitting diode 12. In the embodiment shown here, each light transmissive member 17 is an aspheric lens that is operatively mounted to outer light transmissive member 13 *via* annular extensions 20. In a preferred embodiment, each light transmissive member 17 is fixedly secured to an annular extension 20 *via* a snap-lock mechanism. In alternate embodiments, light transmissive members 17 can be fixedly secured to annular extensions 20 *via* ultrasonic welding, ultrasonic swaging, heat staking, or adhesives.

[0050] In one preferred embodiment, outer light transmissive member 13 is formed of a singularly molded piece of clear, polycarbonate plastic. Similarly, inner light transmissive members 17 are formed of a molded piece of clear, polycarbonate plastic.

[0051] Figure 6 shows a rear top plan view of outer light transmissive member 13 as provided in low beam headlamp 70. Referring to Figure 6, longitudinal axis of headlamp 70 is defined as line $B_1$- $B_1$, and vertical axis of headlamp 70 is defined as line A-A.

[0052] As can be seen here, in this embodiment outer light transmissive member 13 is a lens with a plurality of individual prism optics 25*a,b,c* forming a rectangular array on inner surface 21. By varying the radius, curvature or thickness of the individual prism optics 25*a,b,c*, different desired light patterns can be achieved to satisfy the photometric and luminescence requirements for low beam headlamps as set forth in SAE Standard J1383. For example, in the preferred embodiment shown in Figure 6,

outer light transmissive member 13 has three distinct optical surfaces formed on inner surface 21. The upper portion above longitudinal axis $B_1$- $B_1$ has optical surface 80 and optical surface 81, and the lower portion below longitudinal axis $B_1$- $B_1$ has optical surface 90. In general, optical surface 80 uniformly spreads the light in the horizontal direction at a wide angle, approximately 25-30 degrees left and right of vertical axis A-A. Optical surface 81 spreads the light horizontally in a narrow pattern and vertically, to produce a light pattern approximately eight (8) degrees left to eight (8) degrees right of vertical axis A-A and approximately zero (0) degrees to four (4) degrees up from longitudinal axis $B_1$- $B_1$. Finally, optical surface 90 spreads the light both vertically and horizontally, to produce a light pattern approximately two (2) degrees down from longitudinal axis $B_1$- $B_1$ and approximately two (2) degrees right of vertical axis A-A. In this way, optical surface 90 produces a high intensity area below and to the right of center as required by SAE Standard J1383.

[0053] More specifically, but not intending to be limiting, in the preferred embodiment shown in Figure 6, optical surface 80 comprises a plurality of prism optics 25*a*; optical surface 81 comprises a plurality of prism optics 25*b*; and optical surface 90 comprises a plurality of prism optics 25*c*.

[0054] In Figure 7A, a portion of optical surface 80 is shown in longitudinal cross-sectional view (along line $B_3$- $B_3$). Prism optics 25*a* preferably have a longitudinal cross sectional profile that is generally convex toward light emitting diodes 12. More specifically, as shown here, the longitudinal cross section of prism optics 25*a* has a radius of curvature that is approximately 2.804 mm. In Figure 7B, a portion of optical surface 80 is shown in vertical cross-sectional view (along line A-A). As shown here,

prism optics 25*a* preferably have a vertical cross-sectional profile that is generally linear with a decline angle *m* equivalent to approximately 2.950 degrees down from the horizontal. One of ordinary skill in the art will readily appreciate, however, that the vertical and longitudinal cross section of prism optics 25*a* may each have any suitable radius of curvature or degree of decline such that the light is distributed approximately 25-30 degrees to the left and right of vertical axis A-A.

[0055] In Figure 7C, a portion of optical section 81 is shown in longitudinal cross-sectional view (along line $B_3$- $B_3$). Prism optics 25*b* preferably have a longitudinal cross sectional profile that is generally convex toward light emitting diodes 12. More specifically, in the embodiment shown here, the longitudinal cross section of prism optics 25*b* has a radius of curvature that is approximately 7.182 mm. In Figure 7D, a portion of optical section 81 is shown in vertical cross-sectional view (along line A-A). Prism optics 25*b* preferably have a vertical cross sectional profile that is generally convex toward light emitting diodes 12. More specifically, in the embodiment shown here, the vertical cross section of prism optics 25*b* has a radius of curvature that is approximately 31.965 mm. One of ordinary skill in the art will readily appreciate, however, that the vertical and longitudinal cross section of prism optics 25*b* may each have any suitable radius of curvature such that the light is distributed approximately eight (8) degrees left to eight (8) degrees right of vertical axis A-A and approximately zero (0) degrees to four (4) degrees up from longitudinal axis $B_1$- $B_1$.

[0056] In Figure 7E, a portion of optical surface 90 is shown in longitudinal cross-sectional view (along line $B_2$- $B_2$). Prism optics 25*c* preferably have a longitudinal cross sectional profile that is generally concave toward light emitting diodes 12 with an incline

angle *k* equivalent to approximately 2.950 degrees up from the horizontal. More specifically, in the embodiment shown here, the longitudinal cross section of prism optics 25*c* has a radius of curvature that is approximately 30.000 mm. In Figure 7F, a portion of optical surface 90 is shown in vertical cross-sectional view (along line A-A). In the embodiment shown here, prism optics 25*c* preferably have a vertical cross-sectional profile that is generally linear with an incline angle *j* equivalent to approximately 2.592 degrees up from the horizontal. One of ordinary skill in the art will readily appreciate, however, that the vertical and longitudinal cross section or prism optics 25*c* may each have any suitable radius of curvature or degree of incline such that the light is distributed approximately two (2) degrees down from longitudinal axis $B_1$- $B_1$ and approximately two (2) degrees right of vertical axis A-A.

[0057] As described hereinabove, in a preferred embodiment, headlamp assembly 4 comprises two high beam headlamps 170 in addition to two (2) low beam headlamps 70 (see Figure 1). In general, high beam headlamp 170 comprises the same components as low beam headlamp 70; namely, a housing 6, a reflector subassembly 11, a plurality of high-flux light emitting diodes 12, a support member 9, a plurality of inner light transmissive members 17, and a drive circuit 5. However, rather than an outer light transmissive member 13 as disclosed hereinabove, each high beam headlamp 170 comprises an outer light transmissive member 113 as described hereinbelow.

[0058] Figure 8 illustrates a longitudinal cross-sectional view of light transmissive member 113 along line $X_2$-$X_2$ (see Figure 9) as provided in an individual high beam headlamp 170. As can be seen in Figure 8, light transmissive member 113 has an inner

surface 121 and outer surface 122. Similar to light transmissive member 13, a plurality of annular extensions 20 corresponding to light emitting diodes 12 extends from inner surface 121. Annular extensions 20 are alignment mechanisms for the plurality of inner light transmissive members 17 in the same manner described above in connection with headlamp 70.

[0059] Figure 9 shows a rear top plan view of outer light transmissive member 113. Referring to Figure 9, longitudinal axis of headlamp 170 is defined as line $X_1$-$X_1$, and vertical axis of headlamp 170 is defined as line Y-Y.

[0060] As can be seen here, in a preferred embodiment of high beam headlamp 170, light transmissive member 113 is a lens with a plurality of optical elements formed on inner surface 121. Specifically, and referring to Figure 9, inner surface 121 comprises four distinct optical surfaces 180, 181, 190, 191. Optical surfaces 180, 181, 190, 191 function as converging, or focusing, lenses to satisfy the photometric and luminescence requirements for high beam headlamps as set forth in SAE Standard J1383. In this embodiment for a high beam headlamp, optical surfaces 180, 181, 190, 191 are linear prisms with a conic cross section, whereby each prism is convex toward light emitting diodes 12 to function as a convergent optic.

[0061] For example, referring back to Figure 8, a preferred embodiment of optical surfaces 180, 181, and 190 is illustrated. As shown here, optical surface 180 preferably has a conic cross-sectional profile that is convex toward light emitting diodes 12. Portions of optical surface 180 disposed inside annular extensions 20 collect collimated light rays from the corresponding inner light transmissive member 17 and uniformly distribute the light rays in a horizontal direction, approximately six (6) degrees left and

right of longitudinal axis $X_1$-$X_1$. Additionally, portions of optical surface 180 disposed outside annular extensions 20 collect collimated light rays from reflector subassembly 11 and uniformly distribute the light rays approximately six (6) degrees left and right of vertical axis Y-Y also.

[0062] In this preferred embodiment, but not intending to be limiting, optical surface 180 has radii of curvature that range from approximately 20 mm to 904 mm (a difference of 884 mm). However, one of ordinary skill in the art will readily appreciate that optical surface 180 may have any suitable range of radii of curvature such that the light rays are distributed approximately six (6) degrees left and right of vertical axis Y-Y.

[0063] Referring further to Figure 8, optical surface 181 preferably has a conic cross-sectional profile that is convex toward light emitting diodes 12. Portions of optical surface 181 disposed inside annular extensions 20 collect collimated light rays from the corresponding inner light transmissive member 17 and uniformly distribute the light rays in a horizontal direction, approximately three (3) degrees left and right of vertical axis Y-Y. Additionally, portions of optical surface 181 disposed outside annular extensions 20 collect collimated light rays from reflector subassembly 11 and uniformly distribute the light rays approximately three (3) degrees left and right of vertical axis Y-Y.

[0064] In this preferred embodiment, but not intending to be limiting, optical section 181 has radii of curvature that range from approximately 48 mm to 842 mm (a difference of 794 mm). However, one of ordinary skill in the art will readily appreciate that optical surface 181 may have any suitable range of radii of curvature such that the light rays are distributed approximately three (3) degrees left and right of vertical axis Y-Y.

[0065] Referring further to Figure 8, optical surface 190 preferably has a conic cross-sectional profile that is conic toward light emitting diodes 12. Portions of optical surface 190 disposed inside annular extensions 20 collect collimated light rays from the corresponding inner light transmissive member 17 and uniformly distribute the light rays in a horizontal direction, approximately nine (9) degrees left and right of vertical axis Y-Y. Additionally, portions of optical surface 190 disposed outside annular extensions 20 collect collimated light rays from reflector subassembly 11 and uniformly distribute the light rays approximately nine (9) degrees left and right of vertical axis Y-Y.

[0066] In this preferred embodiment, but not intending to be limiting, optical section 190 has radii of curvature that range from approximately 7 mm to 821 mm (a difference of 814 mm). However, one of ordinary skill in the art will readily appreciate that optical surface 190 may have any suitable range of radii of curvature such that the light rays are distributed approximately nine (9) degrees left and right of vertical axis Y-Y.

[0067] Finally, in Figure 10A, optical section 191 is shown in longitudinal cross-sectional view (along line Z-Z) without light transmissive member 17 and, in Figure 10B, optical section 191 is shown in vertical cross-sectional view (along line V-V) with light transmissive member 17. Optical surface 191, disposed only within the bottom center annular extension 20, collects collimated light rays from the corresponding inner light transmissive member 17 and uniformly distributes the light rays in a horizontal direction, approximately fifteen (15) degrees left and right of vertical axis Y-Y. Additionally, referring to Figure 10B, optical surface 191 has a linear vertical cross-sectional profile

with a decline angle *h* to distribute the light rays vertically approximately one (1) degree downward of longitudinal axis $X_1$-$X_1$.

[0068] In this preferred embodiment, but not intending to be limiting, optical section 190 has radii of curvature that range from approximately 23.09 mm to 44.20 mm (a difference of 21.11 mm). Moreover, in this preferred embodiment, decline angle *h* is equivalent to approximately 1.00 degree down from the horizontal. However, one of ordinary skill in the art will readily appreciate that optical surface 191 may have any suitable range of radii of curvature, or decline angle *h*, such that the light rays are distributed approximately fifteen (15) degrees left and right and approximately one (1) degree downward.

[0069] In practice, when high beam headlamp 170 is switched on, low beam headlamp 70 remains on to supplement the high beam pattern. Low beam headlamp 70 provides supplemental light distribution below the horizontal, for example, 2.5 degrees down and 12 degrees left and right, to satisfy the SAE requirements J1383 for a high beam pattern.

[0070] Figure 11A illustrates a top plan view of housing 6 in a preferred embodiment of low beam headlamp 70. Figure 11B illustrates a bottom plan view of housing 6, and Figure 11C illustrates a cross-sectional view of housing 6 along line D-D. In the preferred embodiments shown and described hereinabove, housing 6 functions as the heat sink. Accordingly, in the embodiment shown here, housing 6 is made of a single piece of aluminum, either die cast or extruded. In an alternate embodiment, die cast zinc can be used for housing 6.

[0071] Housing 6 is exposed to the outside air, thereby allowing the heat transfer provided by housing 6 to be transferred to the air due to convection. In addition, as shown in Figures 11B-11C, a plurality of adjacent, vertically-oriented external cooling fins 16 are disposed on the bottom of housing 6 to enhance the transfer of the heat generated by light emitting diodes 12. In this way, the temperature of light emitting diodes 12 and space 7 are kept sufficiently cool to prevent degradation of the brightness of low beam headlamp 70. By preventing degradation of light emitting diodes 12, the transfer of heat *via* external fins 16 aids headlamp assembly 4 in meeting the requirements of SAE J1383 and the legal criteria set forth in FMVSS 108.

[0072] In a preferred embodiment, low beam headlamp 70 is potted with an epoxy. This not only provides a greater heat sink and ability to withdraw thermal energy directly away from light emitting diodes 12, but also provides protection for light emitting diodes 12 and support member 9 from vibration, fatigue, and moisture.

[0073] Additionally, housing 6 provides a mechanism to mount low beam headlamp 70 onto vehicle 1, such as a truck, tractor and/or a truck trailer. Moreover, apertures 15 are found at the bottom of housing 6. Apertures 15 are function as exit points for electrical wires to connect to circuitry outside low beam headlamp 70. In a preferred embodiment, low beam headlamp has three apertures 15. One of ordinary skill in the art will readily appreciate that apertures 15 can also be standard headlamp terminals and can be arranged in a number of ways. As discussed above, support member 9 is disposed within space 7 and operatively mounted to housing 6. Although not shown here, in a preferred embodiment, housing 6 for high beam headlamp 170 has two apertures 15.

[0074] In an alternate embodiment (not shown), a separate heat sink 14 is utilized. In this embodiment, housing 6 can be made of a material that does not have heat transfer properties, such as polycarbonate plastic. Heat sink 14 is made of aluminum, either die cast or extruded, or any other material with similar heat transfer properties, such as die cast zinc. Heat sink 14 is operatively mounted to the base of housing 6 and support member 9 is mounted to heat sink 14.

[0075] Figure 12 shows drive circuit 5, the drive circuit found in a most preferred embodiment of headlamp assembly 4. In a preferred embodiment of headlamp assembly 4, light emitting diodes 12, in both headlamp 70 and headlamp 170, are connected to a drive circuit 5 in series/parallel; i.e. three strings of two light emitting diodes 12. In this way, a failure of any one string will cause a reduction in light output, but not in the distribution of light.

[0076] Drive circuit 5 is a current-regulating drive circuit with over-voltage protection. Referring to Figure 12, drive circuit 5 provides constant current to three (3) parallel strings of light emitting diodes for two (2) inputs (high/low beam) in the following manner. Drive circuit 5 comprises three of the below-described circuits – one for each parallel string of light emitting diodes. Current is regulated through a voltage range of approximately 9.5V to 16.0V. Current flows through either diode 33 for high beam input, or diode 34 for low beam input, and is filtered by capacitor 36 before input to low drop out (LDO) current regulators 35*a,* 35*b,* 35*c*. LDO current regulators 35*a,* 35*b,* 35*c* are enabled by a small current input. Current regulation is established in LDO current regulators 35*a,* 35*b,* 35*c* by feedback resistor 38 located on the low side of the light emitting diode load. The resistor value of feedback resistor 38 determines current flow

through the string of light emitting diodes and is filtered by capacitors 37*a*, 37*b*, 37*c* on the output of LDO current regulators 35*a*, 35*b*, 35*c*.

[0077] Referring further to Figure 12, as current returns to ground, it passes through HEXFET® switching device 39, which is enabled on/off by an over-voltage sensing circuit. When operating in designed voltage range, approximately 9.5 V-16.0 V, HEXFET® switching device 39 is enabled on and will conduct. When the voltage exceeds upper design limit, a Zener diode sensing component conducts and causes a transistor to pull low (grounding) the gate of HEXFET® switching device 39. This action disables HEXFET® switching device 39 and disconnects the ground or (negative wire) from LDO current regulators 35*a*, 35*b*, 35*c* and load part of circuit 5. When the voltage returns to design voltage range, the above-described process reverses, turning the load and LDO current regulators 35*a*, 35*b*, 35*c* back on.

[0078] In the embodiment illustrated above, drive circuit 5 is mounted on support member 9. However, in alternate embodiments, drive circuit 5 can be separate from support member 9 or even disposed outside low beam headlamp 70 and high beam headlamp 170. Although drive circuit 5, as described above, is a preferred embodiment, alternate circuits with current regulation to protect the light emitting diodes may be used. For example, a circuit that uses a switching power supply followed by a linear current regulator could be employed.

[0079] Figure 13A is a partial vertical cross-sectional view of low beam headlamp 70 that illustrates the manner in which light emitted from light emitting diodes 12 is directed by reflector units 11*a* and inner light transmissive members 17. Figures 13B is a longitudinal cross-sectional view of outer light transmissive member 113 and inner

light transmissive member 17 in high beam headlamp 170, illustrating the manner in which light received from inner light transmissive members 17 is directed by outer transmissive member 113.

[0080] Figure 14, a diagrammatic, top plan view of vehicle 1, illustrates the manner in which headlamp assembly 4 emits light beams in a longitudinal direction parallel to the longitudinal axis of vehicle 1. Figure 14 further illustrates an imaginary surface 8, upon which light beams are projected. Figures 15A-15B illustrate the light pattern emitted by low beam headlamp 70 and high beam headlamp 170, respectively, onto imaginary surface 8.

[0081] For each of the embodiments disclosed herein, the surfaces for reflector units 11*a* and outer light transmissive members 13, 113 were designed and/or constructed using a Non-Uniform Rational B-Splines (NURBS) CAD modeling program, Rhinoceros 2.0 (McNeel Associates, 2001), and the final design and documentation was performed using Unigraphics CAD system.

[0082] One of ordinary skill in the art will readily appreciate that a variety of low beam and high beam headlamp arrays and arrangements are within the scope of this invention. For example, by selectively turning on portions of the light emitting diode headlamp assembly, it is possible to vary the light output to produce not only a high or low beam, but also a fog light or auxiliary high beam or driving light.

[0083] Moreover, in an alternate embodiment of a light emitting diode headlamp assembly according to the invention, a pair of combined low/high beam headlamps comprising a plurality of light emitting diodes as a light source can be utilized. Figures 16A-B illustrate reflector subassembly 211 in an alternate embodiment of the invention,

namely a 7-inch round combined high/low beam headlamp 270. In this embodiment, two headlamps 270 would be used to form a light emitting diode headlamp assembly according to the invention.

[0084] Referring to Figures 16A-B, reflector subassembly 211 combines twelve (12) individual reflector units 211*a* forming a circular arrangement such that each individual reflector unit 211*a* corresponds to one of twelve (12) individual light emitting diodes 212. As in the previously disclosed embodiments, reflector units 211*a* are parabolic reflectors. Approximately six (6) or seven (7) of light emitting diodes 212 are utilized to produce a low beam pattern for the headlamp assembly. The remainder, approximately six (6) or seven (7) of light emitting diodes 212 are utilized to produce a high beam pattern for the headlamp assembly, all in a single headlamp unit. Figure 16C illustrates the corresponding circular arrangement of light emitting diodes 212 on a circular planar substrate 209.

[0085] In still another embodiment (not shown), a reflector subassembly combines twelve (12) individual reflector units forming a circular arrangement such that each individual reflector unit corresponds to one of twelve (12) individual light emitting diodes. Moreover, the size and shape of the combined high/low beam headlamp embodiments can vary. For example, a five (5) inch by seven (7) inch rectangular combined high/low beam headlamp comprises a 2 x 5 array of light emitting diodes and a corresponding 2 x 5 array of parabolic reflector units forming a reflector subassembly (not shown). Again, approximately five or six of light emitting diodes are utilized to produce a low beam pattern for the headlamp assembly. The remainder, approximately five (5) or six (6), of light emitting diodes are utilized to produce a high beam pattern.